Progress report for year 2 of
National Oceanic and Atmospheric Administration (NOAA)
Joint Hurricane Testbed (JHT) Program

Improved SFMR Surface Wind Measurements in Intense Rain Conditions

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Summary:

The airborne stepped frequency microwave radiometer (SFMR) estimates surface winds and rain rate in most weather conditions, particularly in tropical cyclones. However, due to a couple of potential factors, retrieval accuracy has been shown to be degraded in weak-to-moderate winds coupled with strong precipitation. In particular, winds are typically overestimated in such conditions. The objective of this two-year project is to quantify the wind speed errors in such situations and propose a solution that may be implemented for real-time operations. In the first year, the primary goal was to provide an empirically-determined SFMR wind speed bias correction computed from the wind speed and rain rate reported in the HDOB messages. For year two of this project, the main objectives are to evaluate the performance of the wind speed bias correction and to develop an updated geophysical model function that correctly addresses the rain contamination problem. Mid-year results indicate that application of the bias correction model during the 2012 hurricane season improved the overall performance of the SFMR winds used in operations. The proposed work tasks for year two have either been completed or are on schedule as proposed. This mid-year progress report details the year-two accomplishments thus far.

Proposed Timeline of Accomplishments for Year 2 (August 2012 – March 2013):

1) *August – November 2012:* Continue real-time parallel testing of corrected SFMR winds
2) *December 2012:* Evaluate the wind speed bias correction from the 2012 hurricane season
3) *August – December 2012:* Begin working on development of new GMF
4) *March 2013:* Present year-two results at IHC

Progress of Accomplishments (Year 2):

Task 1:

As proposed, SFMR bias corrected wind speeds were calculated in real-time at the National Hurricane Center based on the operational HDOB data during the 2012 hurricane season. With the assistance of Drs. Chris Landsea and Michael Brennan, these data were available to forecasters and were used in forecast discussions throughout the season. Generally, these data were well-received and provided assistance in diagnosing surface wind speeds during the season.

Task 2:

Evaluating the performance of the data collected during the 2012 hurricane season is two-fold. Similarly to the year-one task of expanding the SFMR-GPS dropsonde database, these SFMR data, which were from both NOAA and Air Force Reserve missions, are paired with matching GPS dropsonde surface-adjusted wind speed data. There are a total of 582 usable pairs with a majority of these pairs (518, 89%) having rain rates less than 10 mm hr^{-1} and 64 pairs (11%) having rain rates greater than 10 mm hr^{-1}. Table 1 provides the details of the uncorrected (UC) and bias-corrected (BC) binned pairs with wind speed (WS) in m s^{-1} and rain rate (RR) in mm hr^{-1}. Bins that have less than three pairs do not have any statistical calculations included.

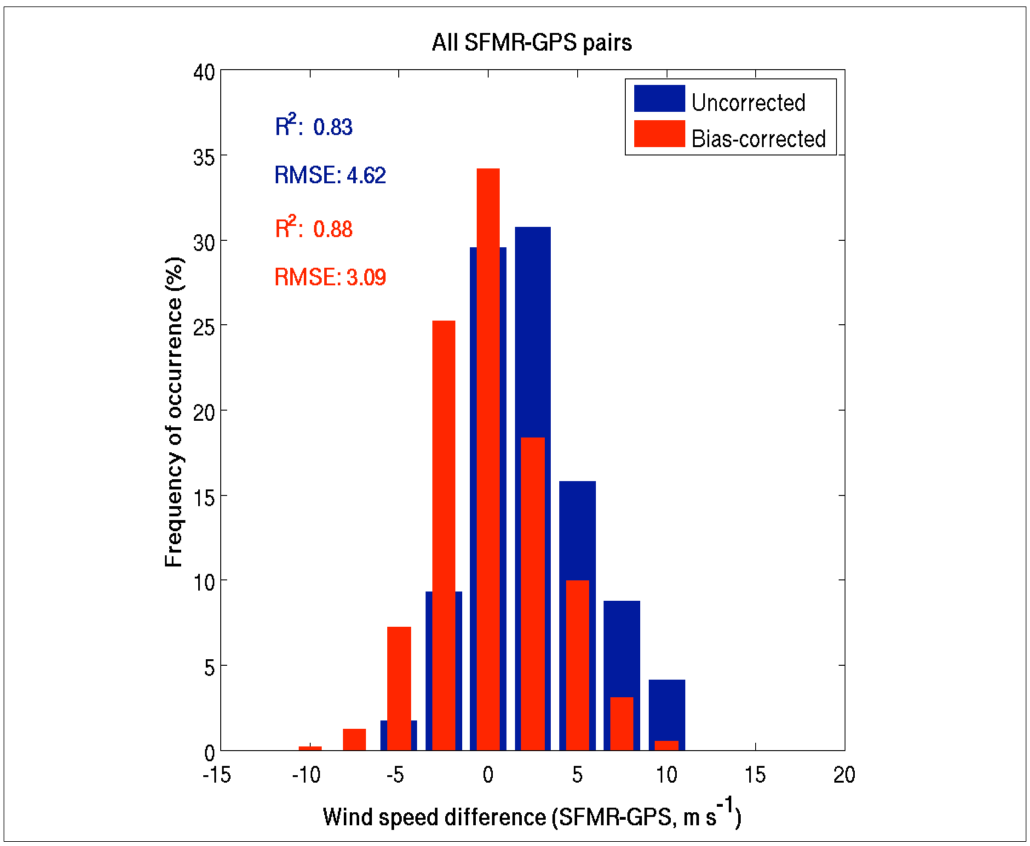
Table 1. SFMR rain rate (mm hr^{-1}) and wind speed (m s^{-1}) bins are displayed and include the mean SFMR – GPS wind speed difference per each bin. Values in parentheses indicate the bias-corrected differences. Counts per each bin are also included on the second line of each bin.

	WS < 17	**17 ≤ WS < 25**	**25 ≤ WS < 33**	**33 ≤ WS < 50**	**WS ≥ 50**
RR < 10	**2.74 (0.22)** **281 (322)**	**1.44 (-0.39)** **186 (155)**	**1.32 (0.41)** **37 (32)**	**2.24 (1.49)** **14 (9)**	**-- (--)** **0 (0)**
10 ≤ RR < 20	**7.91 (3.64)** **5 (10)**	**4.03 (0.59)** **17 (17)**	**2.42 (-0.39)** **16 (14)**	**0.45 (--)** **4 (1)**	**-- (--)** **0 (0)**
20 ≤ RR < 30	**-- (--)** **0 (1)**	**-- (--)** **1 (1)**	**3.33 (0.64)** **6 (7)**	**2.49 (-1.11)** **5 (3)**	**-- (--)** **0 (0)**
RR ≥ 30	**-- (--)** **0 (1)**	**-- (1.96)** **1 (4)**	**4.67 (-1.00)** **7 (4)**	**-- (--)** **2 (1)**	**-- (--)** **0 (0)**

Based on Table 1, it is clearly seen that the BC averages for each bin pair are lower than the UC data. In many instances, the BC value is between -1 and 1 whereas many of the UC data are greater than two. While not included in Table 1, standard deviations for the UC and BC data are similar. However, overall standard

deviations are between 0.5 and 1.0 m s^{-1} higher for the UC data than the BC data. Because there are so few pairs present at higher rain rates, there is also a higher uncertainty, but the mean values clearly indicate that the BC has reduced the difference between the SFMR and GPS dropsondes at all wind speeds and rain rates with valid data.

This is also seen when comparing frequency histograms of the wind speed difference between the two wind speed quantities. These histograms were calculated for all data pairs for 2012 and for 2012 pairs with SFMR rain rates greater than 10 mm hr^{-1}. Figures 1 and 2 provide the total data histogram and



rain-only histograms, respectively, with the blue bars indicating UC pairs and red bars indicating BC pairs.

Figure 1. Histogram of SFMR-GPS wind speeds for all pairs for uncorrected (blue) and bias-corrected (red) data. Data are plotted as frequency percentages.

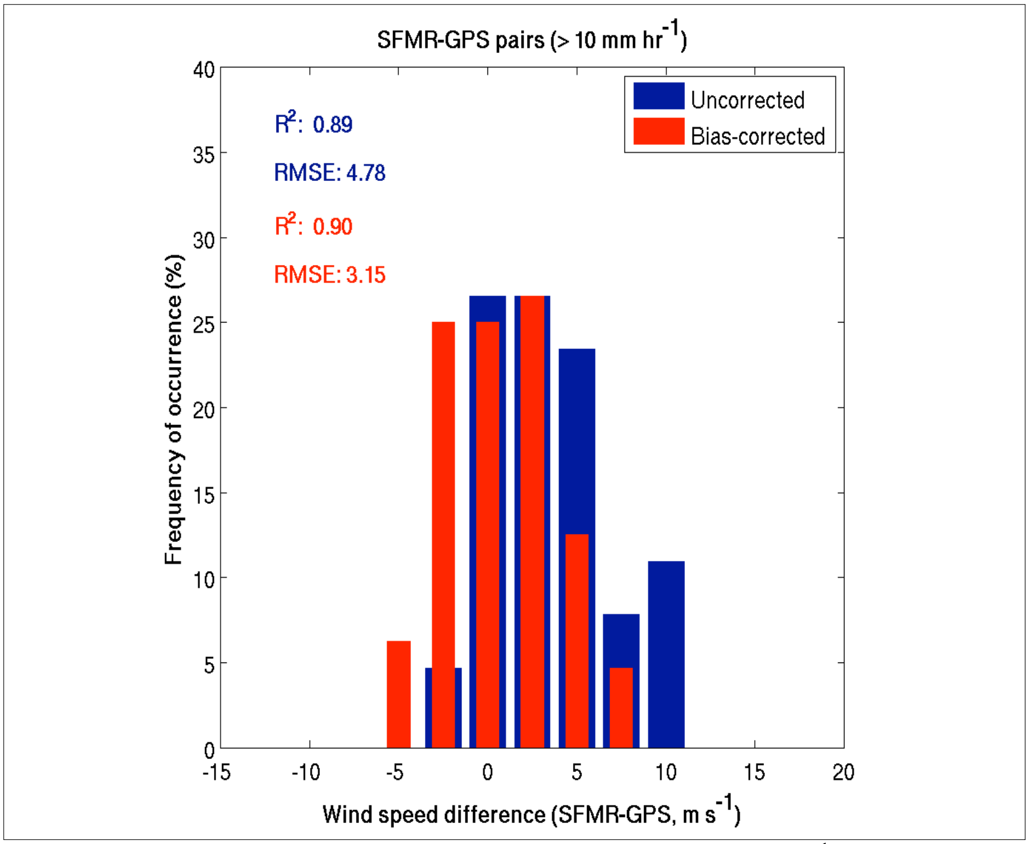


Figure 2. Same as Fig. 1 but for pairs with SFMR rain rates greater than 10 mm hr^{-1}.

In Figure 1, a clear shift toward zero occurs when comparing the BC data against the UC data. The overall mean for the UC data is 2.30 m s^{-1} and the overall mean for the BC data is 0.08 m s^{-1}. Also, the difference in these populations is statistically significant at 95% confidence based on a student's t-test. The correlation coefficient increases by 0.5 and the RMSE decreases by over 1.5 m s^{-1} for the BC data, indicating that the BC data better compares to the GPS dropsonde wind speeds. For data between -2.5 and 2.5 m s^{-1}, the BC population has 78% of its data in this range while the UC data has 69% in this range. In general, this histogram indicates that applying the BC for all data provides a better relationship between the SFMR wind speed and the GPS surface adjusted wind speed.

Figure 2 provides insight into data that were collected in the presence of rain. The overall mean of the UC data is 3.48 m s^{-1} while the overall mean of the BC data is 0.68 m s^{-1}, and similarly to the entire dataset, these populations differ significantly at 95% confidence according to a student's t-test. The correlation coefficient increases slightly but the RMSE also decreases by over 1.5 m s^{-1} for the BC data, indicating that the BC data better compares to the GPS dropsonde wind speeds in the presence of rain. The portion of the UC data between -2.5 and 2.5 m s^{-1} is 57% while the portion of BC data within the same range is 76%. This result is important because it indicates that in the presence of rain, the

SFMR wind speeds (in relation to the GPS wind speeds) are improved by over 20%. From the statistical analysis provided for the total sample and the rain-only sample, it is clear that the bias-corrected wind speeds are more closely correlated with GPS dropsonde surface-adjusted wind speeds and provides a better representation of the surface wind speed in the presence of rain.

Task 3:

While the bias correction discussed in the previous section provides a reduction in the overestimated wind speeds, it does not fully address the issues caused by rain. The current GMF provides overestimates of wind speed due to an incorrect relationship between absorption and precipitation. In order to address this rain problem in the GMF, the wind versus emissivity relationship in rain-free conditions is calculated. The rain versus absorption relationship then can be improved to provide a complete and updated GMF that reduces the wind speed errors in the presence of rain.

For the wind versus emissivity relationship, the 2012 wind speed pairs mentioned in the previous section are added to the existing database. Emissivities are calculated using the brightness temperatures associated with each measurement. Because there are fewer data pairs at higher wind speeds (> 35 m s^{-1}) without rain and because these wind speeds are not as affected by rain, the new wind-emissivity relationship is derived from a combination of rain-free pairs at wind speeds < 35 m s^{-1} and all-rain conditions > 35 m s^{-1}. According to these specifics, there were over 1400 pairs used in the creation of this updated model. Figure 3 displays the updated wind-emissivity model against the current model.

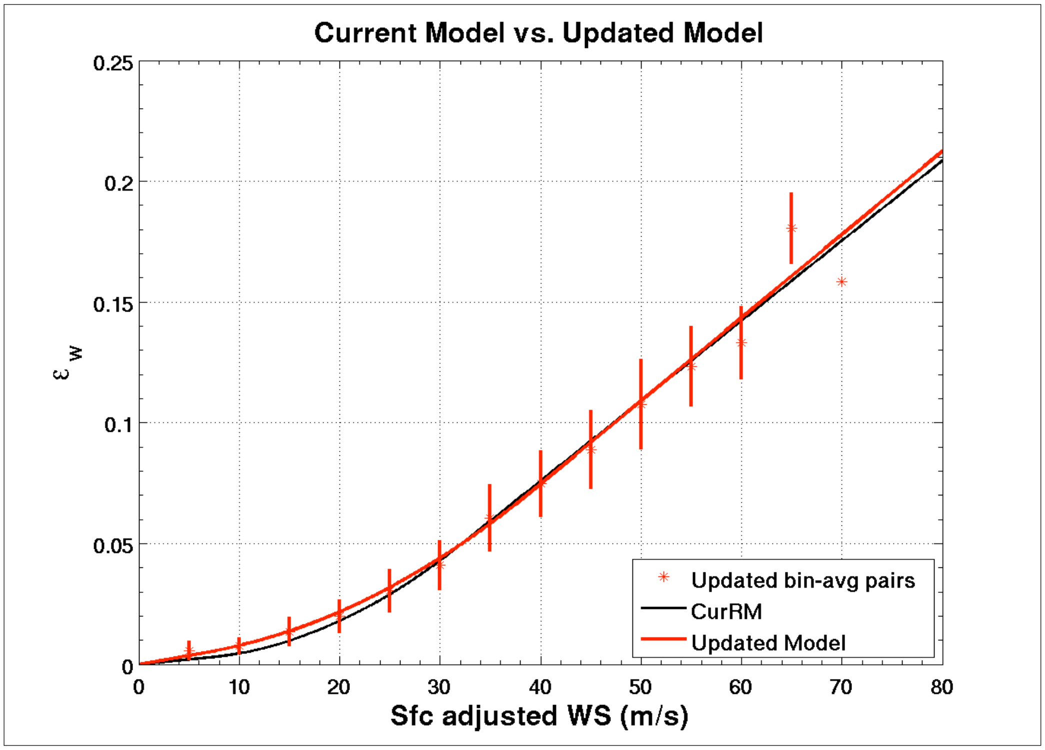


Figure 3. Wind versus emissivity models for the current relationship (black) and the updated relationship (red). The red asterisks indicate the bin-averaged means with error bars provided for 95% confidence intervals.

There are some slight changes at the lower wind speeds (< 25 m s^{-1}) in Fig. 3, but generally, the updated model is similar to the current model, especially at higher wind speeds. This is an expected result because in rain-free conditions, less of the signal is absorbed in the atmosphere and more of the emissivity signal is detected by the SFMR. At the higher wind speeds, the emissivity signal is more discernible in the presence of rain and is much less affected during the retrieval.

For the updated rain-absorption model in the GMF, the objective is to obtain a better representation of the SFMR rain rate. In order to complete this task, several other independent measurements of rain are used to develop a new calculation of rain. NOAA Tail Doppler (TA) radar reflectivity data along with Precipitation Imaging Probe (PIP) data are used in comparison with the SFMR rain rates. Radial profiles of these three rain measurements are collected from several hurricanes with available data. The data portions chosen were limited by the amount of available PIP data as this instrument was only on one aircraft. Column-mean reflectivities from the TA are provided for values below the freezing level and are indicative of the rain column. Figure 4 provides one example of how these data compare with one another.

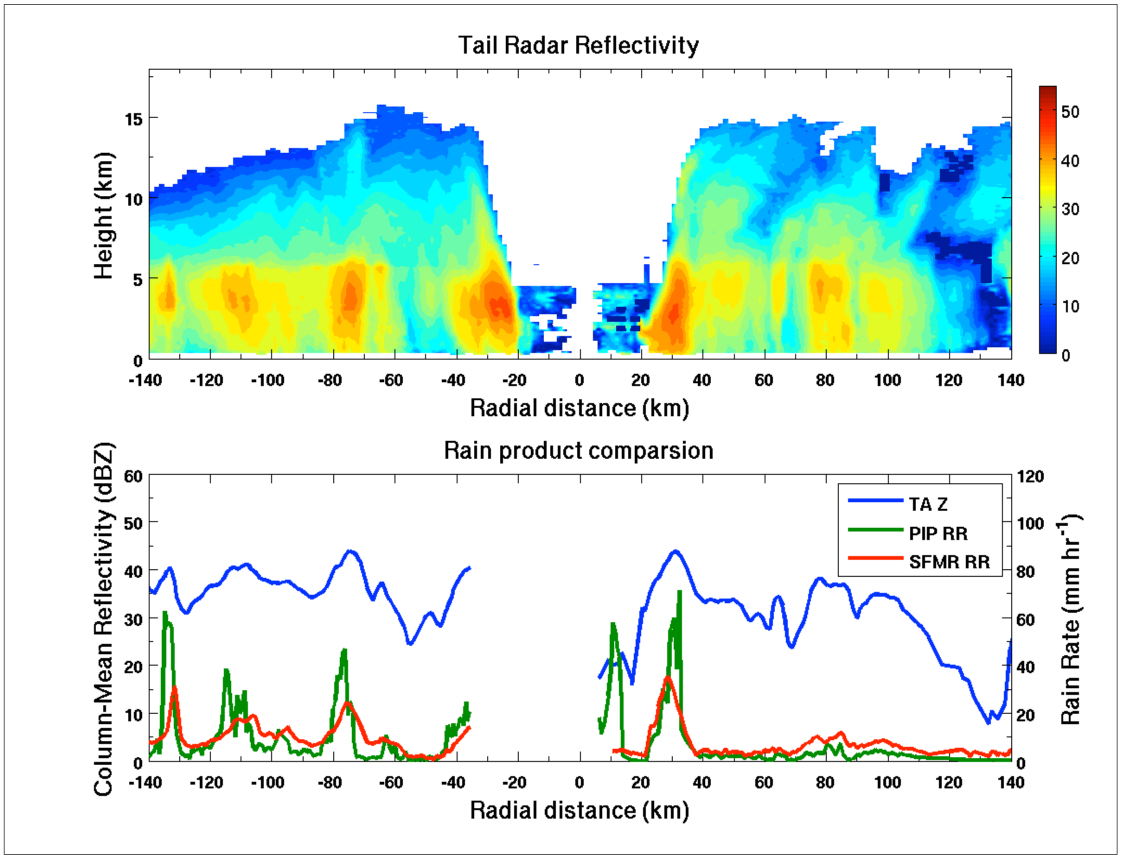


Figure 4. A single NOAA WP-3D penetration of Hurricane Katrina from 28 August, 2005 is shown. In the top panel, Tail Doppler radar reflectivity (dBZ) is shown as a function of radial distance from the center. In the bottom panel, the column-mean radar reflectivity (blue, dBZ), PIP rain rate (green, mm hr^{-1}) and SFMR rain rate (red, mm hr^{-1}) are shown over the same radial distances as the top panel.

At least from this particular example, it is possible to see the rain produced in the eyewall (top panel) as well as some of the outer rainbands. The corresponding rain rate values from the SFMR and PIP correspond well in trend, but the SFMR rain rate is likely underestimated due to the amount of the signal that is attributed to absorption. Based on the dataset of these profiles, a new Z-R (reflectivity-rain rate) relationship will be derived from PIP rain rate and the radar reflectivity.

Task 4:

This work was presented at the 2013 Interdepartmental Hurricane Conference by the PI as outlined in the original proposal.

Remaining year-two tasks:

1) *March – April 2013:* Coordinate installation of statistical correction on the NOAA and Air

Force Reserve aircraft

2) *May 2013:* Complete development of updated, coupled GMF

3) *June – August 2013:* Test and evaluate SFMR winds computed from updated GMF for all AFRC and NOAA missions

4) *August 2013:* Provide software and documentation to NOAA/AOC, 53rd WRS, and ProSensing, Inc. for possible real-time implementation